Forward-backward multiplicity correlations in the wounded nucleon model

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Abstract

The forward-backward multiplicity correlation strength is calculated for arbitrary nucleus-nucleus collision in the framework of the wounded nucleon model. Discussion of our results in the context of the recent STAR data in $AuAu$ collisions at $\sqrt{s} = 200$ GeV is presented. It is suggested that the observed (i) growth of the correlation coefficient with centrality and (ii) approximately flat pseudorapidity dependence of the correlation strength for central collisions are due to the fluctuations of the number of wounded nucleons at a given centrality bin.

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1 Introduction

Recently the STAR collaboration announced the results [1] on the forward-backward multiplicity correlations in nucleus-nucleus collisions. It was found that the correlation strength (defined below) was larger than in an elementary proton-proton collisions and it remains constant (at least for the most central collisions) across the measured midrapidity region. This result was interpreted in the framework of the color glass condensate [2] or dual parton [3] models, which suggests the possible formation of high density partonic matter in central $AuAu$ collisions at $\sqrt{s} = 200$

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GeV. Other theoretical investigations concerning the problem of forward-backward multiplicity correlations in hadronic collisions can be found in Refs. [4–12].

The main difficulty, however, is to distinguish between correlations arising from the presence of the quark-gluon plasma and correlations that do not depend on this new phenomenon. These need to be understood, controlled and subtracted in order to access the true signal of the quark-gluon plasma. The natural ground to study this problem is the wounded nucleon model [13]. Indeed, it is the simplest superposition model in which a nucleus-nucleus collision is constructed from an elementary nucleon-nucleon collisions. More precisely, the number of produced particles in nucleus-nucleus collision is proportional to the number of wounded nucleons, i.e., nucleons that underwent at least one inelastic collision. A Monte Carlo analysis of this problem in the very simplified wounded nucleon model was already presented in Ref. [4].

Our main conclusion is that the STAR data [1] can be naturally understood in the wounded nucleon model (at least for the most central collisions). We conclude that the observed growth of the correlation coefficient with centrality and approximately flat pseudorapidity dependence of the correlation strength are due to the fluctuations of the number of wounded nucleons at a given centrality bin.

The correlation coefficient (or correlation strength) b is defined as

$$b = \frac{\langle n_B n_F \rangle - \langle n_B \rangle \langle n_F \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2} \equiv \frac{U}{D}, \tag{1}$$

where n_B and n_F are event by event particle multiplicities in backward B and forward F pseudorapidity[1] intervals, respectively. The main ingredients which allow to evaluate b in the wounded nucleon model are (i) recently obtained pseudorapidity particle density from a wounded nucleon $\rho(\eta)$ and (ii) particle multiplicity distributions measured in pp collisions in different forward and backward intervals. The fragmentation function $\rho(\eta)$, shown in Fig. 1, was obtained by analysing the PHOBOS data on dAu collisions [14] at $\sqrt{s} = 200$ GeV in the wounded nucleon model [15] and the wounded quark-diquark model[2] [16]. In a completely independent way, mainly based on the recent NA49 collaboration data [17], analogous wounded nucleon fragmentation function was constructed in Ref. [18]. For the multiplicity distributions measured in pp collisions we take the negative binomial (NB) fits [19]

$$P(n, \bar{n}, k) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \left(\frac{\bar{n}}{k}\right)^n \left(1 + \frac{\bar{n}}{k}\right)^{-n-k}, \tag{2}$$

where $\bar{n}$ is the average multiplicity and $1/k$ measures deviation from Poisson distribution.

[1]Our discussion is valid for any longitudinal variable, not necessarily pseudorapidity.

[2]In this case $\rho(\eta) = 1.2F(\eta) + 0.8U(\eta)$, where $F(\eta)$ and $U(\eta)$ are the particle densities from wounded and unwounded constituents, respectively.

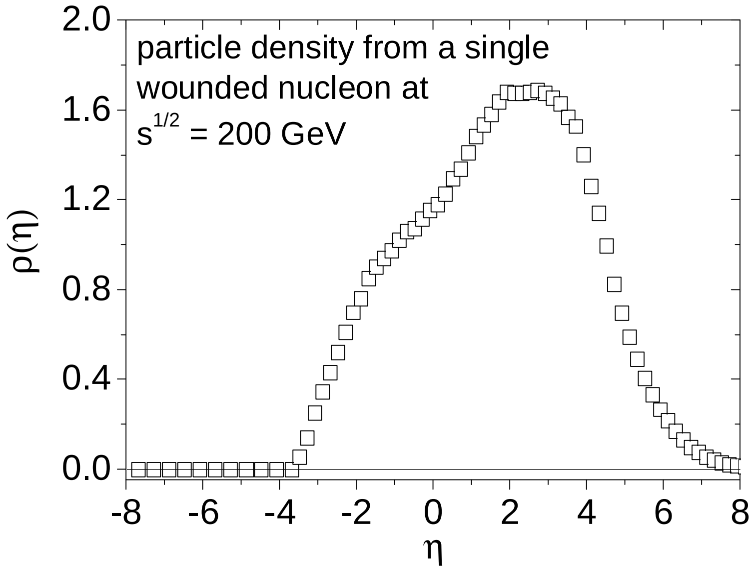

Figure 1: A wounded nucleon fragmentation function at $\sqrt{s} = 200$ GeV c.m. energy.

In the next section the correlation coefficient b for the collision of two arbitrary nuclei is derived. In section 3 we focus on the collision of two symmetric nuclei and look closer at the midrapidity and fragmentation regions, where b can be written in a particularly simple form. Our results are discussed in the context of the recent STAR data in section 4 and section 5 where also some comments are included. In the last section our conclusions are listed.

2 Model

The problem is to calculate the correlation coefficient (1) in two given pseudorapidity regions B and F under assumption that the contribution to the multiplicity in these two intervals is provided by independent contributions from left- and right-moving wounded nucleons. It is similar to the assumption of independent hadronization of strings in the dual parton model [3]. The picture of independent left- and right-moving sources of particles is the main assumption of the wounded nucleon model. There are many phenomenological and experimental evidences supporting this idea [15, 18, 20].

It is convenient to construct the generating function

$$H\left(z_B, z_F\right) = \sum_{n_B, n_F} P\left(n_B, n_F\right) z_B^{n_B} z_F^{n_F}, \tag{3}$$

where $P\left(n_B, n_F\right)$ is the probability to find n_B particles in B and n_F in F. In general

we may have many sources of particles (wounded nucleons), thus $P(n_B, n_F)$ can be expressed as

$$P(n_B, n_F) = \sum_{w_L, w_R} W(w_L, w_R) P(n_B, n_F; w_L, w_R), \tag{4}$$

where $W(w_L, w_R)$ is the probability distribution of the numbers of wounded nucleons moving left w_L and right w_R, respectively. $P(n_B, n_F; w_L, w_R)$ is the probability to find n_B particles in B and n_F in F under condition of w_L and w_R wounded nucleons in left- and right-moving nucleus, respectively.

As derived in the Appendix, the generating function (3) reads

$$\begin{aligned} H(z_B, z_F) = \sum_{w_L, w_R} W(w_L, w_R) \left\{1 + \frac{\bar{n}}{k}\left[p_{LB}(1 - z_B) + p_{LF}(1 - z_F)\right]\right\}^{-kw_L/2} \times \\ \times \left\{1 + \frac{\bar{n}}{k}\left[p_{RB}(1 - z_B) + p_{RF}(1 - z_F)\right]\right\}^{-kw_R/2}, \end{aligned} \tag{5}$$

where p_{RF} denotes the probability that a particle originating from the right-moving wounded nucleon goes to F interval, under the condition that this particle was found either in B or F (and analogous for p_{RB}, p_{LB} and p_{LF}). These probabilities satisfy natural conditions

$$p_{LB} + p_{LF} = 1, \quad p_{RB} + p_{RF} = 1. \tag{6}$$

These numbers can be easily calculated. Indeed, they depend only on positions and sizes of B and F as well as the shape of the wounded nucleon fragmentation function $\rho(\eta)$. For instance, p_{RF} has the form

$$p_{RF} = \frac{\int_F \rho(\eta)\, d\eta}{\int_{B+F} \rho(\eta)\, d\eta}. \tag{7}$$

The parameters $\bar{n}$ and k come from the NB distribution fit (2) to the pp multiplicity distribution data in the combined interval $B+F$. These parameters are well known for various energies and different pseudorapidity intervals [19]. Moreover

$$\bar{n} = 2\int_{B+F} \rho(\eta)\, d\eta. \tag{8}$$

It is worth to notice that formula (5) contains all information about the multiplicities in B and F, as well as their dependence on the number of wounded nucleons.

Using definitions (1) and (3) we obtain [$b \equiv U/D$]:

$$\begin{aligned} U &= \left[\frac{\partial^2 H}{\partial z_B \partial z_F} - \frac{\partial H}{\partial z_B}\frac{\partial H}{\partial z_F}\right]_{z_B, z_F = 1}, \\ D &= \left[\frac{\partial^2 H}{\partial z_F^2} + \frac{\partial H}{\partial z_F} - \left(\frac{\partial H}{\partial z_F}\right)^2\right]_{z_B, z_F = 1}. \end{aligned} \tag{9}$$

Performing appropriate differentiations we obtain

$$\frac{4U}{\bar{n}^2} = p_{LB}p_{LF}\left[\left\langle w_L^2\right\rangle - \langle w_L\rangle^2 + \frac{2\langle w_L\rangle}{k}\right] + p_{RB}p_{RF}\left[\left\langle w_R^2\right\rangle - \langle w_R\rangle^2 + \frac{2\langle w_R\rangle}{k}\right] + \\ + (p_{LB}p_{RF} + p_{LF}p_{RB})\left[\langle w_L w_R\rangle - \langle w_L\rangle\langle w_R\rangle\right], \tag{10}$$

and

$$\frac{4D}{\bar{n}^2} = p_{LF}^2\left[\left\langle w_L^2\right\rangle - \langle w_L\rangle^2 + \frac{2\langle w_L\rangle}{k}\right] + p_{RF}^2\left[\left\langle w_R^2\right\rangle - \langle w_R\rangle^2 + \frac{2\langle w_R\rangle}{k}\right] + \\ + 2p_{LF}p_{RF}\left[\langle w_L w_R\rangle - \langle w_L\rangle\langle w_R\rangle\right] + 2\frac{p_{LF}\langle w_L\rangle + p_{RF}\langle w_R\rangle}{\bar{n}}. \tag{11}$$

In the above expressions $\langle ...\rangle$ represents the average with respect to $W(w_L, w_R)$. For instance $\langle w_L\rangle$ is the average number of wounded nucleons in the left-moving nucleus.

3 Fully symmetric case

The result presented in the previous section is valid for any colliding nuclei. In case of symmetric collisions we of course have $\langle w_L\rangle = \langle w_R\rangle$ and $\langle w_L^2\rangle = \langle w_R^2\rangle$. Moreover, studying correlations in symmetric (around $\eta = 0$) intervals, i.e., $p_{LB} = p_{RF} \equiv p$ and $p_{LF} = p_{RB} = 1 - p$, we obtain

$$b = \frac{C_1\left[\langle w_R^2\rangle - \langle w_R\rangle^2 + 2\langle w_R\rangle/k\right] + C_2\left[\langle w_L w_R\rangle - \langle w_R\rangle^2\right]}{C_2\left[\langle w_R^2\rangle - \langle w_R\rangle^2 + 2\langle w_R\rangle/k\right] + C_1\left[\langle w_L w_R\rangle - \langle w_R\rangle^2\right] + 2\langle w_R\rangle/\bar{n}}, \tag{12}$$

where

$$C_1 = 2p(1-p), \quad C_2 = 1 - C_1. \tag{13}$$

It is worth to notice that formula (12) simplifies for two cases.

(i) Midrapidity. Considering two narrow rapidity intervals B and F around $\eta = 0$ we have $p \approx 0.5$. It leads to a particularly simple expression

$$b = 1 - \left[1 + \frac{\bar{n}}{4}\left(\frac{2}{k} + \frac{\langle w^2\rangle - \langle w\rangle^2}{\langle w\rangle}\right)\right]^{-1}, \tag{14}$$

where $w = w_L + w_R$ is the number of wounded nucleons in both colliding nuclei. This formula allows to notice the growth of b with increasing scaled variance of the number of wounded nucleons $\left\langle [w - \langle w\rangle]^2\right\rangle / \langle w\rangle$.

(ii) Fragmentation region. Assuming that intervals B and F are separated enough so that F can be populated only by right-moving wounded nucleons and

B only by the left-moving ones, that is $p = 1$, we obtain

$$b = \frac{\langle w_L w_R \rangle - \langle w_R \rangle^2}{\langle w_R \rangle} \left[\frac{2}{\bar{n}} + \frac{2}{k} + \frac{\langle w_R^2 \rangle - \langle w_R \rangle^2}{\langle w_R \rangle} \right]^{-1} . \qquad (15)$$

In this case $b > 0$ only due to the fluctuations of the number of wounded nucleons, i.e., $b = 0$ if $\langle w_L w_R \rangle = \langle w_R \rangle^2$.

This closes the theoretical discussion of the problem.

4 Results

Recently the STAR collaboration presented results [1] on correlation coefficient b for $AuAu$ collisions at $\sqrt{s} = 200$ GeV. The backward $B = (-\frac{\Delta\eta}{2} - 0.1, -\frac{\Delta\eta}{2} + 0.1)$ and forward $F = (\frac{\Delta\eta}{2} - 0.1, \frac{\Delta\eta}{2} + 0.1)$ intervals of width 0.2 each were located symmetrically around $\eta = 0$ with the distance $\Delta\eta$ between bin centres ranging from 0.2 to 1.8 with an interval of 0.2. The measurement was performed for different centrality classes defined via the number of produced particles in the central rapidity region.[3]

As argued in Ref. [22] different centrality selections (e.g., via impact parameter, number of wounded nucleons, number of produced particles) give the same average number of wounded nucleons $\langle w \rangle$. However, as was shown in Ref. [4], they lead to rather different $\Omega \equiv [\langle w^2 \rangle - \langle w \rangle^2] / \langle w \rangle$, except the most central collisions, where Ω weakly depends on the centrality class definition. In consequence, direct comparison of our result (12) with the STAR data can be performed only for the most central collisions. In case of non-central collisions the comparison is not straightforward. Indeed, wounded nucleon model does not describe correctly the multiplicities in $AuAu$ collisions, thus not allowing to impose experimental centrality class cuts on the number of produced particles.

We performed our calculations with the centrality class definition via the number of wounded nucleons $w = w_L + w_R$ in both colliding nuclei (obviously the impact parameter fluctuations are also included). We performed Monte-Carlo calculations [23] for five centrality class selections: $0 - 10\%$, $10 - 20\%$, $20 - 30\%$, $30 - 40\%$ and $40 - 50\%$ what correspond to $w \geq 275$, $275 > w \geq 197$, $197 > w \geq 139$, $139 > w \geq 94$ and $94 > w \geq 60$, respectively. The corresponding results for $\langle w_R \rangle$, $\langle w_R^2 \rangle$, $\langle w_L w_R \rangle$ and Ω are presented in Table 1. In our MC calculations for the nuclear density profile we took the standard Woods-Saxon approximation with the nuclear radius $R = 6.38$ fm and the skin depth $d = 0.535$ fm [24]. For the nucleon-nucleon

[3] For instance $0 - 10\%$ centrality class corresponds to events with the number of produced particles (in the central region) larger then 430 [21].

%	$\langle w_R \rangle$	$\langle w_R^2 \rangle$	$\langle w_L w_R \rangle$	Ω
0-10	163	26841	26793	3.04
10-20	116.8	13803	13723	2.07
20-30	83.1	7015	6938	1.71
30-40	57.5	3378	3315	1.40
40-50	37.83	1478	1432	1.26

Table 1: The MC results for $\langle w_R \rangle$, $\langle w_R^2 \rangle$, $\langle w_L w_R \rangle$ and $\Omega = [\langle w^2 \rangle - \langle w \rangle^2] / \langle w \rangle$ corresponding to five 10% centrality classes defined via the number of wounded nucleons $w = w_L + w_R$ in both colliding nuclei.

interaction profile we used the black disk approximation[4], i.e., the interaction takes place only if the transverse distance between two colliding nucleons is smaller than $\sqrt{\sigma/\pi}$, with the total inelastic pp cross section $\sigma = 42$ mb.

In Fig. 2 the calculated correlation coefficient b (12) for $0-10\%$ and $10-20\%$ vs. the distance $\Delta\eta$ between bin centres is compared with the STAR data [21]. Taking Eq. (7) into account we obtain $p = 0.51, 0.52, 0.55, 0.56, 0.58$ for $\Delta\eta = 0.2, 0.6, 1.0, 1.4, 1.8$, respectively. NB distribution fits to pp multiplicity data in the midrapidity region give approximately constant $\bar{n} = 0.96$ (central plateau) and $k = 1.8$ [19].[5] It is interesting to note that for the $0-10\%$ most central events, where direct comparison with the data is possible, the wounded nucleon model can explain more than 85% of the effect.

In Fig. 3 the correlation coefficient b (12) for $20-30\%$, $30-40\%$ and $40-50\%$ centrality events vs. the distance $\Delta\eta$ between bin centres is shown. The wounded nucleon model predicts larger values of b than observed, however, as explained at the beginning of this section in case of non-central collisions the direct comparison with the data cannot be performed [unknown precise value of $[\langle w^2 \rangle - \langle w \rangle^2] / \langle w \rangle$, see Eq. (14)]. The main experimental finding, however, that the correlation coefficient is approximately flat[6] in the midrapidity region as a function of $\Delta\eta$ is very well reproduced in the wounded nucleon model. This feature of the model can be easily understood from Eq. (14). Indeed, $\bar{n}$ and k are approximately constant (central plateau) in the midrapidity region and the value of p is close to 0.5, which is a consequence of the longitudinal structure of the wounded nucleon fragmentation

[4]We also performed calculations for the Gaussian approximation. We observe the week dependence of our results on the pp interaction profile.

[5]From Ref. [19] it may be concluded that k is slightly increasing to $k \approx 2$ for $\Delta\eta = 1.8$. This effect, however, practically does not influence numerical values of b.

[6]This is not true for the $40-50\%$ centrality events. We will come back to this point in the next section.

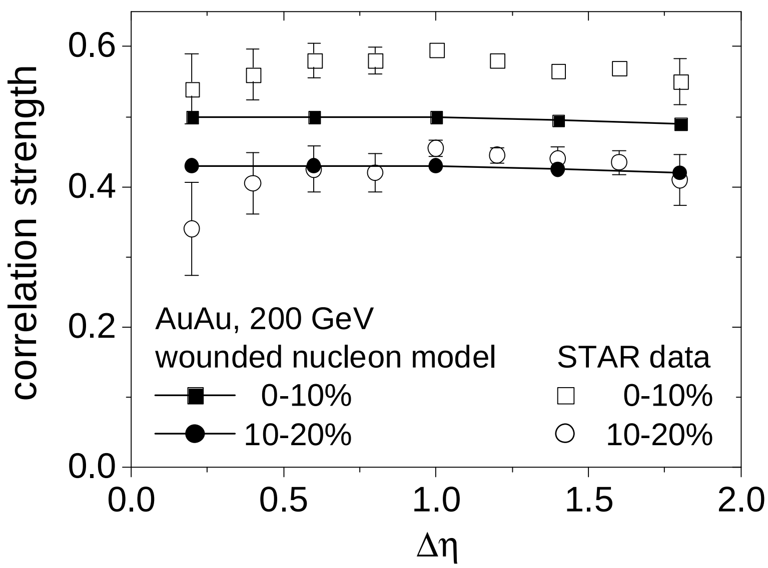

Figure 2: The STAR data points compared with the results of the wounded nucleon model for the correlation coefficient b for two most central events vs. the distance $\Delta\eta$ between bin centres. The width of each bin equals 0.2.

function, shown in Fig. 1.

In Fig. 4 the correlation coefficient b (12) for $0-10\%$, $10-20\%$ and $30-40\%$ centrality events vs. the distance $\Delta\eta$ in the broader range is shown. Taking Eqs. (7) and (8) we obtain $(p, \bar{n}) = (0.7, 0.97)$, $(0.85, 0.79)$, $(1, 0.53)$ for $\Delta\eta = 4$, 6, 8, respectively. The values of parameter k are not known precisely within these intervals, however, as can be concluded from [19] they should not be larger then $k = 4$. As shown in Fig. 4, where the results are presented for $k = 1.8$ and $k = 4$ for $\Delta\eta \geq 4$, this uncertainty practically does not influence our final results. The reduction of the correlation coefficient b at $\Delta\eta = 8$ (at this point $b \approx 0$ for peripheral collisions) is fully determined by the suppression of particle production from a wounded nucleon to the backward hemisphere[7], see Fig. 1.

5 Comments

Following comments are in order.

(a) It is well-know that the wounded nucleon model significantly underestimates the multiplicities in $AuAu$ collisions [25]. Contrary to the model assumption multi-

[7]For instance, assuming that the contribution from a wounded nucleon is symmetric around $\eta = 0$ (i.e. $p = 0.5$ at any $\Delta\eta$) we would obtain $b \approx 0.2$ at $\Delta\eta = 8$ for $30 - 40\%$ centrality events.

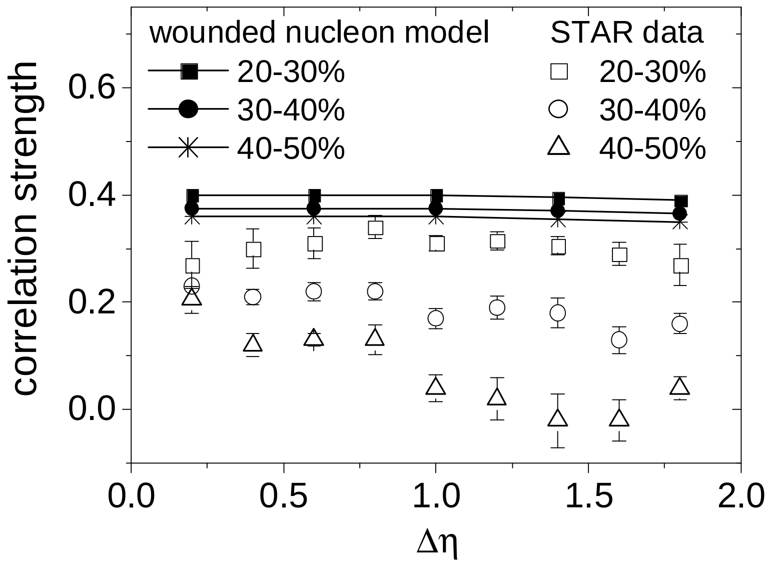

Figure 3: The STAR data and the results of the wounded nucleon model for the correlation coefficient b for non-central events vs. the distance $\Delta\eta$ between bin centres. As explained in the text in this case direct comparison between data and model cannot be performed.

plicity from a wounded nucleon depends on the number of collisions it underwent. In order to take this effect into account we multiplied $\bar{n}$ and k by the ratio γ of the measured multiplicity in $AuAu$ collisions [25] to the prediction of the wounded nucleon model $\bar{n}w/2$ [13]. For the $0-10\%$ most central collisions we approximately obtain $\gamma \approx 1.6$ and consequently $b \approx 0.59$, which is in very good agreement with the measured value, see Fig. 2.

(b) As seen in Figs. 2, 3 and from Eq. (14) the correlation coefficient calculated in the wounded nucleon model is always flat in the midrapidity region in contrast to the $30-40\%$, $40-50\%$ peripheral $AuAu$ or pp collisions. In the present paper we suggest that the fluctuation of the number of wounded nucleons may be responsible for the large value of the forward-backward correlation coefficient in central $AuAu$ collisions. For peripheral collisions, however, this source of correlations is becoming less important (the value of $[\langle w^2\rangle - \langle w\rangle^2]/\langle w\rangle$ decreases) and obviously the mechanism responsible for correlations in elementary pp collisions play a major role. In our approach we cannot describe the precise shape of the correlation coefficient in pp collisions[8] as a function of $\Delta\eta$, thus at the same time our approach is not applicable to the peripheral $AuAu$ collisions.

[8]Neglecting fluctuations in Eq. (14) we obtain in the midrapidity region the constant value of $b \approx 0.2$.

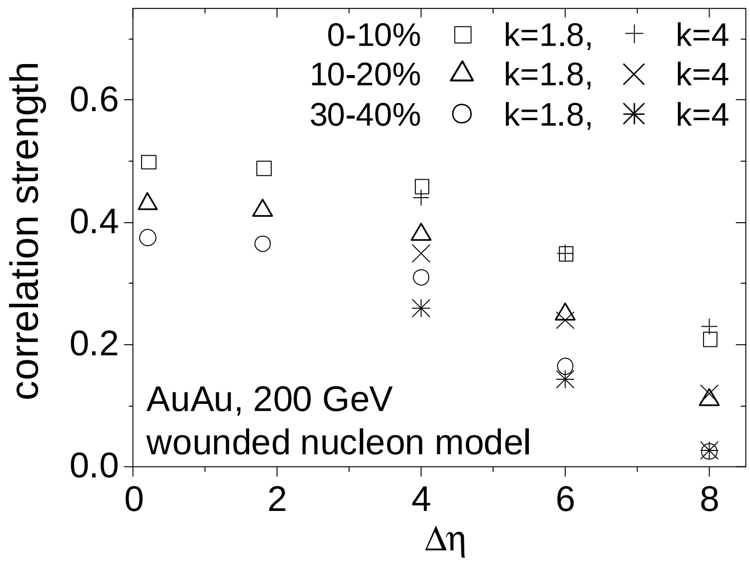

Figure 4: Wounded nucleon model prediction for the correlation coefficient b in the broad range of the distance $\Delta\eta$ between bin centres. The width of each bin equals 0.2.

(c) Encouraged by the success of our approach we also provide the prediction for the correlation coefficient b for the most central $PbPb$ collisions at the LHC energy $\sqrt{s} = 5500$ GeV. Performing appropriate MC calculations[9] (described in the previous section) we obtained for the $0-10\%$ centrality events the following value of $[\langle w^2\rangle - \langle w\rangle^2]/\langle w\rangle = 2.55$. Once the parameters $\bar{n}$ and k are measured at a given $B+F$ interval in pp collisions, the predictions for the correlation coefficient b in the midrapidity region can be easily obtained from Eq. (14). As an example we present the result for b in the midrapidity region with the forward and backward intervals identical to those at the STAR measurement. The needed parameters $\bar{n} \approx 1.7$ [26] and $k \approx 1.5$ [19, 27] are taken from extrapolations to the LHC energy. In consequence we obtain $b \approx 0.6$ or $b \approx 0.7$ if the correction to the wounded nucleon model, discussed at the beginning of this section, is taken into account. Our value is close to the prediction reported in Ref. [6]. However, in our approach the large value of b is only due to the fluctuation in the number of wounded nucleons, which if neglected (it corresponds to pp collisions) we obtain $b \approx 0.35$ in contrast to the value reported in Ref. [6].

(d) The wounded nucleon pseudorapidity fragmentation function, shown in Fig. 1, extends far beyond its own hemisphere. As discussed in the previous section this feature is partially responsible for the approximately constant value of b in the midra-

[9]Here $R = 6.62$ fm, $d = 0.546$ fm and $\sigma = 67$ mb [24].

pidity region. It is interesting to note that similar longitudinal structure is present in the dual parton model (DPM) [3], where the long longitudinally extended strings are stretched between quarks and diquarks of the projectile and target, respectively. In general, models that can explain the long-range forward-backward correlations are models that introduce long extended objects in rapidity [2, 3, 5–7, 10]. Moreover, in DPM the growth of the correlation coefficient is due to the fluctuations in the number of elementary inelastic collisions, which is similar to the fluctuations of the number of wounded nucleons present in our approach. Therefore it is not surprising that the two models lead to similar qualitative results [1]. However, the wounded nucleon model is in better agreement with data.

(e) Similar longitudinal structure provides the QCD inspired color glass condensate model (CGC) [28], which includes many features of DPM. In this approach [2] the long extended color flux tubes and the fluctuations of the number of gluons allow to understand the main features of the STAR data. Moreover, it was shown recently [29] that the soft ridge structure observed at RHIC [30] can be naturally understood in the CGC/glasma motivated phenomenology, which is rather difficult to obtain in the framework of the wounded nucleon model. This problem is currently under our investigation.

(f) It would be interesting to perform similar calculation of the correlation coefficient b in the framework of the wounded quark-diquark model [16, 31], which proved to be quite successful in description of particle production in pp, dAu, $CuCu$ and $AuAu$ collisions. In this model the number of produced particles is proportional to the number of wounded quarks and diquarks, which are assumed to be the constituents of each nucleon. Here the growth of the correlation coefficient is due to the fluctuations of the number of wounded quarks and diquarks at a given centrality bin.

(g) In the present approach we implicitly assume that particles are produced directly from wounded nucleons. It would be interesting to check an effect of intermediate resonances (clusters) production. We expect this effect to influence the forward-backward multiplicity correlations in the midrapidity region for peripheral $AuAu$ and pp collisions.

6 Conclusions

Our conclusions can be formulated as follows.

(i) We have studied the forward-backward multiplicity correlations in the framework of the wounded nucleon model [13]. In this model particles are produced independently from the left- and right-moving nucleons that interacted in inelastic

way at least once. An analytical expression for the correlation coefficient (strength) for the collision of two arbitrary nuclei and at any forward F and backward B intervals was derived.

(ii) The main ingredients of our approach are: recently obtained long extended in pseudorapidity wounded nucleon fragmentation function [15, 16] and the multiplicity distributions measured in proton-proton collisions described by a negative binomial distribution.

(iii) In the midrapidity region correlation coefficient can be written in a particularly simple form (14). This expression allows to explain the growth of the correlation coefficient with increasing scaled variance $\left\langle [w - \langle w \rangle]^2 \right\rangle / \langle w \rangle$ of the number of wounded nucleons w in both colliding nuclei.

(iv) We have performed explicit calculations for $AuAu$ collisions at $\sqrt{s} = 200$ GeV. The backward/forward intervals were chosen according to the recent STAR measurement. Growth of the correlation coefficient with centrality as well as almost no pseudorapidity dependence in the midrapidity region was observed. Our results are in good qualitative agreement with the STAR data, although exact comparison can be performed only for the most central collisions.

(v) Finally, predictions for the values of the correlation coefficient in the broad range of pseudorapidity were presented.

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A Appendix: Generating function

Let $P_L(n_{LB}, n_{LF})$ be the probability that a left-moving wounded nucleon contributes n_{LB} particles into B and n_{LF} particles into F interval [and analogous distribution $P_R(n_{RB}, n_{RF})$ for a right-moving source]. The probability to find $n_B = n_{LB} + n_{RB}$ particles in B and $n_F = n_{LF} + n_{RF}$ particles in F in case of one left- and one right-moving wounded nucleon is given by

$$P(n_B, n_F) = \sum_{\substack{n_{LB}, n_{LF} \\ n_{RB}, n_{RF}}} P_L(n_{LB}, n_{LF}) P_R(n_{RB}, n_{RF}) \delta^{n_B}_{n_{LB}+n_{RB}} \delta^{n_F}_{n_{LF}+n_{RF}}, \tag{16}$$

and the generating function ($1,1$ means one left- and one right-moving wounded nucleon)

$$H\left(z_B,z_F;1,1\right)=\sum_{n_B,n_F}P\left(n_B,n_F\right)z_B^{n_B}z_F^{n_F}=H_L\left(z_B,z_F\right)H_R\left(z_B,z_F\right), \tag{17}$$

with

$$\begin{aligned} H_L\left(z_B,z_F\right) &= \sum_{n_{LB},n_{LF}} P_L(n_{LB},n_{LF}) z_B^{n_{LB}} z_F^{n_{LF}}, \\ H_R\left(z_B,z_F\right) &= \sum_{n_{RB},n_{RF}} P_R(n_{RB},n_{RF}) z_B^{n_{RB}} z_F^{n_{RF}}. \end{aligned} \tag{18}$$

It is easy to check that in case of w_L left-moving and w_R right-moving wounded nucleons we obtain

$$H\left(z_B,z_F;w_L,w_R\right)=\left[H_L\left(z_B,z_F\right)\right]^{w_L}\left[H_R\left(z_B,z_F\right)\right]^{w_R}. \tag{19}$$

Suppose that $P_1(n)$ is the multiplicity distribution from a single wounded nucleon in the combined interval $B+F$. Then

$$P_L(n_{LB},n_{LF})=P_1(n=n_{LB}+n_{LF})\frac{(n_{LB}+n_{LF})!}{n_{LB}!n_{LF}!}\left(p_{LB}\right)^{n_{LB}}\left(p_{LF}\right)^{n_{LF}}, \tag{20}$$

where p_{LB} and p_{LF} are defined in section 2. In consequence

$$H_L\left(z_B,z_F\right)=\sum\nolimits_n P_1(n)\left[p_{LB}z_B+p_{LF}z_F\right]^n. \tag{21}$$

Performing analogous calculations for the right moving part

$$H_R\left(z_B,z_F\right)=\sum\nolimits_n P_1(n)\left[p_{RB}z_B+p_{RF}z_F\right]^n. \tag{22}$$

Assuming that the multiplicity distribution measured in proton-proton collision is described by a NB distribution with $\bar{n}$ and k (in the combined interval $B+F$), it is easy to show that $P_1(n)$ (from a wounded nucleon) is given by a NB distribution with $\bar{n}/2$ and $k/2$ [32]. Then using

$$\sum\nolimits_n P_1(n)\xi^n=\left(1+\frac{\bar{n}(1-\xi)}{k}\right)^{-k/2}, \tag{23}$$

we obtain

$$\begin{aligned} H\left(z_B,z_F;w_L,w_R\right) = &\left\{1+\frac{\bar{n}}{k}\left[1-p_{LB}z_B-p_{LF}z_F\right]\right\}^{-kw_L/2}\times \\ &\times\left\{1+\frac{\bar{n}}{k}\left[1-p_{RB}z_B-p_{RF}z_F\right]\right\}^{-kw_R/2}. \end{aligned} \tag{24}$$

Summing over $W(w_L,w_R)$, i.e., the probability distribution of the number of wounded nucleons, and taking (6) into account we finally obtain (5).

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